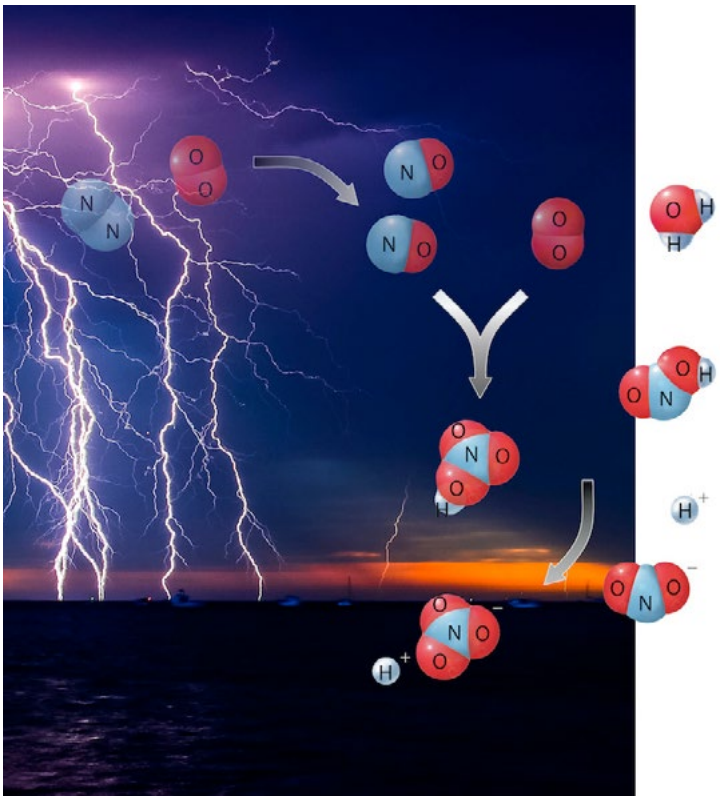


Chapter 9

How Chemicals React

THE MAIN IDEA

Atoms change partners during a chemical reaction.

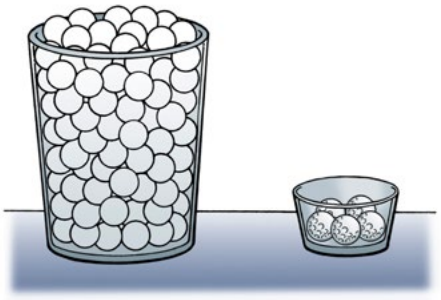
9.2 Measuring Molecules

In any chemical reaction, a specific number of reactants react to form a specific number of products. For example, when carbon and oxygen combine to form carbon dioxide, they always combine in the ratio of one carbon atom to one oxygen molecule. A chemist who wants to carry out this reaction in the laboratory would be wasting chemicals and money if she were to try to combine, say, four carbon atoms for every one oxygen molecule. The excess carbon atoms would have no oxygen molecules to react with and would remain unchanged.

But how is it possible to measure out a specific number of atoms or molecules? Rather than counting these particles individually, chemists can use a scale that measures the mass of bulk quantities. Because different atoms and molecules have different masses, however, a chemist can't simply measure out equal masses of each. Say, for example, he needs the same number of carbon atoms as oxygen molecules. Measuring equal masses of the two materials would not provide equal numbers.

Consider this analogy: You know that Ping-Pong balls are much lighter than golf balls. So, if you were to measure out 1 kilogram of each, you understand that you would need many more Ping-Pong balls to create a full kilogram, as shown in **Figure 9.1**. You understand that the *number* of something and the mass of something are two different things and that they should never be confused with each other.

Because different atoms and molecules have different masses, there are different numbers of them in a sample of the same mass. Carbon atoms are less massive than oxygen molecules. That's why there are more carbon atoms in a 1-gram sample of carbon than there are oxygen molecules in a 1-gram sample of oxygen. So clearly, equal masses of these two substances do not yield equal numbers of carbon atoms and oxygen molecules.



Equal masses

Λ Figure 9.1

For the same mass, the number of Ping-Pong balls is greater than the number of golf balls because a single Ping-Pong ball is lighter than a single golf ball.

READING CHECK

Samples of two different materials have the same mass. Do they necessarily have the same number of atoms?

FOR YOUR INFORMATION

The number of atoms in your breath is about 100 times the number of breaths in the atmosphere.

If we know the *relative masses* of different materials, we can measure equal numbers. Golf balls, for example, are about 20 times more massive than Ping-Pong balls, which is to say the relative mass of Ping-Pong balls to golf balls is 20 to 1. Measuring out 20 times as much mass of golf balls as of Ping-Pong balls, therefore, gives equal numbers of each, as is shown in **Figure 9.2.**

Where do we turn to find the relative masses of atoms and molecules? You guessed it! The masses of elements shown in the periodic table are relative masses. Using these masses, we can measure out equal numbers of atoms or molecules.

For example, as illustrated in **Figure 9.3**, the mass of carbon is 12.011 amu. (As discussed in Section 4.4, one *atomic mass unit* (amu) equals 1.661×10^{-24} gram.) The **formula mass** of a substance is the sum of the atomic masses of the elements in its chemical formula. Consider, the formula mass of an oxygen molecule, O_2, is about 32 amu (15.999 amu + 15.999 amu). A carbon atom, therefore, is about 12/32 as massive as an oxygen molecule. To measure out equal numbers of carbon atoms and oxygen molecules, we could measure out 12 grams of carbon and 32 grams of molecular oxygen. Any proportion equal to 12/32, such as 6/16 or 3/8, would also do. For example, 3 grams of carbon would have the same number of particles as 8 grams of molecular oxygen.

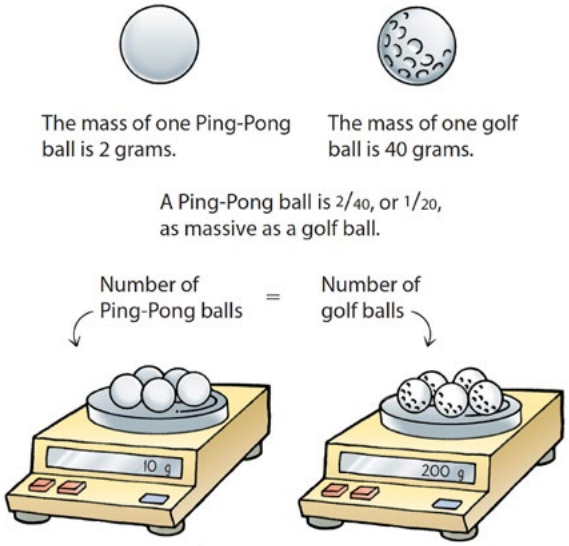


Figure 9.2 >

The number of golf balls in 200 grams of golf balls equals the number of Ping-Pong balls in 10 grams of Ping-Pong balls.

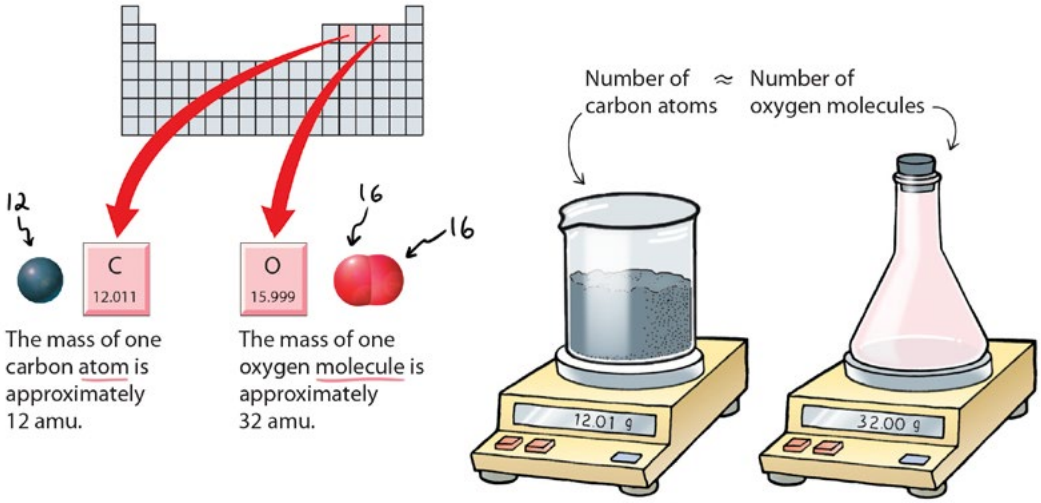


Figure 9.3 >

Measuring carbon, C, and oxygen, O_2, in a 12:32 ratio provides the same number of particles. The same would be true if they were measured in a 6 to 16 ratio, or even a 3 to 8 ratio. (Note: the volumes shown are exaggerated. Twelve grams of solid carbon would occupy only about 5 mL, while 32 grams of gaseous oxygen, O_2, would occupy about 22.4 L.)

CONCEPT **CHECK**

A customer wants to buy a 1:1 mixture of blue and red jelly beans. Each blue bean is twice as massive as each red bean. If the clerk measures out 5 pounds of red beans, how many pounds of blue beans must she measure out?

CHECK YOUR ANSWER

Because each blue jelly bean has twice the mass of each red one, the clerk needs to measure out twice as much mass of blues in order to have the same count, which means 10 pounds of the blues. If the clerk did not know that the blue beans were twice as massive as the red ones, she would not know what mass of blues was needed for the 1:1 ratio.

CONCEPT **CHECK**

1. Reacting 3 grams of carbon, C, with 8 grams of molecular oxygen, O_2, results in 11 grams of carbon dioxide, CO_2. Does it follow that 1.5 grams of carbon will react with 4 grams of oxygen to form 5.5 grams of carbon dioxide?

2. Would reacting 5 grams of carbon with 8 grams of oxygen also result in 11 grams of carbon dioxide?

CHECK YOUR ANSWER

1. Yes, it does. The quantities are only half as much, but their ratio is the same as when 11 grams of carbon dioxide is formed: 1.5/4/5.5 = 3/8/11.

2. A common error of many students is to think that no reaction will occur if the proper ratios of reactants are not provided. You should realize, however, that in this reaction, only 3 of the 5 grams of carbon can react with 8 grams of oxygen to form 11 grams of carbon dioxide. Two grams of carbon will be unreacted after the reaction. Reacting this remaining 2 grams of carbon would require more oxygen.